APPENDIX A

1. English translation of Japanese Application No. 2000-180719

2. Declaration of Kiyoaki Isozaki

DECLARATION

I, Kiyoaki ISOZAKI , a national of Japan, c/o Asamura Patent Office of 331-340, New Ohtemachi Building, 2-1, Ohtemachi-2-chome, Chiyoda-ku, Tokyo, Japan do hereby solemnly and sincerely declare:-

1) THAT I am well acquainted with the Japanese language and English language, and

2) THAT the attached is a full, true, accurate and faithful translation into the English language made by me of Japanese Patent Application No. 2000-180719 .

The undersigned declares further that all statements made herein of his own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under section 1001, of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issuing thereon.

Signed this 21st day of August , 2003 .

Kiyoaki Isozaki

Kiyoaki ISOZAKI

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[Title of the Invention] ELECTRONIC DEVICE

[Scope of Claim(s) for a Patent] 12

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[Title of the Invention] ELECTRONIC DEVICE

[Scope of Claim for a Patent]

[Claim 1]

An electronic device having a structure bonded by using a paste, which is composed by a mixture of metal balls containing a single-element metal, alloys, compounds, or a mixture thereof, and solder balls containing Sn as a component, the structure having compounds composed of components of the metal balls and components of solder balls.

[Claim 2]

The electronic device according to claim 1, wherein the solder balls contain at least one of eutectic Sn-Cu solder balls, eutectic Sn-Ag solder balls, eutectic Sn-Ag-Cu solder balls, and solder balls formed by adding one or more of In, Zn, and Bi to these solder balls.

[Claim 3]

The electronic device according to claim 1, wherein the metal balls are applied by Au plating, or Ni-Au plating, or single-element metal plating of Sn, or alloy plating containing Sn.

[Claim 4]

The electronic device according to any one of claims 1 to 3, wherein the metal balls are ones containing Cu, Cu alloys, Cu8Sn5 compounds, or a mixture of these substances.

[Claim 5]

An electronic device having a structure bonded by using a paste composed of balls containing one or more of metal balls, which

contain a single-element metal, alloys, compounds, or a mixture thereof and to which Sn plating, Sn alloy plating, or the like is applied.

[Claim 6]

The electronic device according to claim 5, wherein the balls contain one or more of the metal balls, to which single-element metal plating of Sn, or alloy plating containing Sn is applied, or to a substrate of which Ni plating, Ni-Au plating, or the like is applied.

[Claim 7]

The electronic device according to claim 5 or 6, wherein the metal balls are ones containing Cu, Cu alloys, Cu6Sn5 compounds, Au-Sn compounds, or a mixture thereof.

[Claim 8]

An electronic device comprising

electronic parts bonded by forming a Cu-Sn alloy layer by the use of a paste, in which metal balls made from one of Cu, Ag, Au, Al, Ni and Cu-Sn alloy are mixed with solder balls containing Sn as a component, and

a circuit board solder-bonded by the use of electrodes of the electronic parts and a Sn-Ag base solder, a Sn-Ag-Cu base solder, a Sn-Cu base solder, or a solder formed by adding Bi, In, or the like to these solders.

[Claim 9]

The electronic device according to claim 8, wherein the metal balls are applied by Au plating, Ni-Au plating, or Sn plating.

[Claim 10]

The electronic device according to any one of claims 1 to 9, wherein the metal balls are obtained by subjecting surfaces of resin balls to any one of Ni/Au plating, Ni/Sn plating, Ni/Cu/Sn plating, Cu/Ni plating, Cu/Ni/Au plating, and Cu/Ni/Sn plating.

[Claim 11]

An electronic device, in which electronic parts, in which a Cu-Sn alloy and a Ni-Sn alloy are partly formed by making up a metallized outermost surface of a bonded surface of a first member from any one of Cu, Ni, and Ni/Au, making up a metallized outermost surface of a bonded surface of a second member connected to the first member from either of Cu/Sn and Ni/Sn, and bonding the first and second members to each other through Sn, are connected to a circuit board by using a Sn-Ag base solder, a Sn-Ag-Cu base solder, a Sn-Cu base solder, or a solder formed by adding Bi, In, or the like thereto.

[Claim 12]

The electronic device according to claim 10 or 11, wherein the metallized outermost surfaces of the bonded surfaces of the first and second members are roughened by etching, a Sn base solder paste is applied on one of the first and second members, and the first and second members are bonded to each other.

[Detailed Description of the Invention]

[0001]

[TECHNICAL FILED, TO WHICH THE INVENTION BELONGS]

The present invention relates to a technique for performing

solder bonding through the use of a temperature hierarchy.

[0002]

[PRIOR ART]

In Sn-Pb base solders, temperature-hierarchical bonding has been made possible by performing soldering with the use of high-temperature solders, such as Pb-rich Pb-5Sn (melting point: 314 to 310 °C), Pb-10Sn (melting point: 302 to 275 °C), or the like, at temperatures around 330 °C and then performing bonding with the use of a low-temperature eutectic Sn-37Pb solder (183 °C) without melting the soldered portions. Such temperature-hierarchical bonding is applied to semiconductor devices, in which chips are die-bonded, semiconductor devices, such as BGA, CSP, or the like, in which chips are flip-chip-bonded, or the like. That is, it is temperature-hierarchical bonding of a solder used inside a semiconductor device and a further solder used for bonding the semiconductor device itself to a substrate.

[0003]

[PROBLEMS TO BE SOLVED BY THE INVENTION]

At present, it is promoted to make all solder-bonded portions Pb-free.

[0004]

The main current of Pb-free solders is constituted by eutectic Sn-Ag base solders, eutectic Sn-Ag-Cu base solders, and eutectic Sn-Cu base solders, and soldering temperatures in surface mounting are 235 to 250 °C at maximum. There is no solder for temperature hierarchy on a high-temperature side that can be used in combination

with these solders. While Sn-5Sb (240 to 232 °C) is available as a most possible composition, there is no solder capable of ensuring a high reliability without melting the composition, when taking into account that a substrate placed in a reflow furnace disperses in temperature. Also, while Au-20Sn (melting point: 280 °C) is known as a high-temperature solder, it is limitative in use because it is hard and expensive in cost. Since the solder is hard and possible to break a Si chip, it is not used especially in bonding of a Si chip to a material having a different coefficient of thermal expansion from that of the chip, and in bonding of a large-sized chip.

[0005]

It is an object of the invention to provide an electronic device fabricated with a completely new solder bonding. In particular, the object is to realize solder bonding on a high-temperature side, in temperature-hierarchical bonding.

[0006]

[MEASURE FOR SOLVING THE PROBLEMS]

In order to attain the above-mentioned object, the invention is constituted according to the claims.

[0007]

Incidentally, taking account of temperature-hierarchical bonding, a solder having already been bonded on a high-temperature side can adequately ensure strength enough to withstand in a process at the time of later solder bonding provided that even when a part of the solder melts, the remainder of the solder does not melt.

Hereupon, we carried out bonding by the use of a paste being a mixture of Cu (or Ag, Au, surface-treated Al, or resins) balls, or these balls, to surfaces of which Sn plating or the like is applied, and a small amount of Sn base solder balls. Thereby, Cu balls in places, in which they are in contact with or come close to one another, react with a molten Sn therearound to form Cu6Sn5 in diffusion bonding between Cu and Sn, whereby bonding between Cu balls can be ensured. Since the portions subjected to diffusion bonding do not melt at soldering temperatures of around 250 °C, bonding is maintained in at least the portions to prevent the portions from coming off when they are mounted to a circuit board later.

[0008]

[PRACTICAL FORM OF THE INVENTION]

Practical forms of the invention will be described below.

[0009]

(Embodiment 1)

Fig. 1 shows the concept of a bonded structure in the invention. This figure also shows a condition before soldering and a condition after soldering.

[0010]

An upper portion of Fig. 1 shows an example of use of a paste, in which Cu balls 1 (or balls of Ag, Au, Al, Ni, Cu-Sn alloys, and the like, or these balls, to which Au plating, Ni/Au plating, or the like, is applied, or these balls, to which Sn plating, or the like, is applied, can also do) with a particle size of about 30 µm and Sn solder balls 2 (melting point: 232 °C) with a particle

size of about 30 μm are appropriately dispersed in small quantities via a flux 4. When this paste is subjected to reflow at 250 °C, the Sn solder balls 2 melt, and molten Sn 3 spreads in a manner to wet the Cu balls 1 and becomes present between the Cu balls 1 relatively uniformly.

[0011]

Subsequently, a compound (Cu6Sn5) of Cu and Sn is formed by performing short-time aging at 200 °C or thereabout, and the Cu balls 1 are bonded together with the compound therebetween. Because the melting point of the compound is as high as about 630 °C and the mechanical properties of the compound are not poor, there is no problem in strength. If the aging is performed for a long time at high temperatures, however, a Cu3Sn compound comes to grow on the Cu side. Because Cu3Sn is hard and brittle in mechanical properties, it is necessary to control this in a manner to cause this not to grow.

[0012]

Since, as described above, the Cu balls 1 are bonded together with the compound (Cu6Sn5) therebetween, neither bonded portion (Cu6Sn5) nor the Cu balls 1 melt and so reliability in bonding can be ensured even when passed through a reflow furnace at 240 °C or thereabout after the bonding. In addition, taking account of the reliability in bonding among the Cu balls 1, it is preferred that the compound (Cu6Sn5) be formed to have a thickness of about 1 to 2 μm. Also, in bonding the Cu balls 1 together by the compound, it is preferred that the Cu balls be put near in a state of contact

by adjusting an amount of Sn being melted. Also, the disused flux 4 is cleaned.

[0013]

A lower portion of Fig. 1 shows an example, in which the above-described Cu balls 1 are subjected to Sn plating or the like with 10 to 20 μm in thickness. Even in this case, the same result as that in the above-mentioned example can be also obtained. The plating treatment makes the molten Sn3 easy to wet and spread along the balls, thus making it easy for the Cu balls 1 to be spaced equally from one another. In addition, since the plating exposes surfaces of the Cu balls such that the films thereof are broken during reflow, the same compound (Cu_6Sn_5) as that described above is generated.

[0014]

Subsequently, electronic parts, such as packages, parts, and the like, having this bonded structure are mounted on a printed circuit board. At this time, temperature-hierarchical bonding becomes necessary. For example, after printing of a Sn-3Ag-0.5Cu solder paste (melting point: 221 to 217 °C) on connection terminals of the printed circuit board and mounting of electronic parts, such as packages, parts, and the like, bonding is achieved by performing reflow at 240 °C in the atmosphere (possible also in nitrogen). While this Sn-(2.5 to 3.5) mass % Ag-(0.5 to 1.0) mass % Cu is treated as a standard solder that replaces conventional eutectic Sn-Pb solders, it is higher in melting point than the eutectic Sn-Pb solders, and so development of Pb-free solders of higher melting point and high reliability has been a subject. Since, as described

above, strength is ensured between Cu and Cu6Sn5 on a high-temperature side, on which bonding has been achieved, and the compound is as high as 630 °C in melting point, no large forces act on the parts themselves during reflow and the parts will not come off. Therefore, even when the Sn-(2.5 to 3.5) mass % Ag-(0.5 to 1.0) mass % Cu is used for bonding to a printed circuit board, it is possible to realize temperature-hierarchical bonding on a higher temperature side than the bonding. In addition, the flux in this case is of a RMA (Rosin Mild Activated) type for non-cleaning application, or a RA (Rosin Activated) type for cleaning application, and both cleaning and non-cleaning are possible.

[0015]

(Embodiment 2)

In Fig. 2, a component 13 is bonded to a substrate 6 by means of an Au-20Sn solder 7 or the like, and after wire bonding 8, a periphery of a cap 9, which is formed by applying a Ni-Au plating to Fe-Ni or the like, is bonded, by way of reflow, to the substrate with the use of the above-described paste of a type for non-cleaning application. On this occasion, it is desired that the flux be non-chlorine based and bonding be performed in a nitrogen-atmosphere, but when wet performance cannot be ensured, seal with a weak-activity rosin of the RMA type will not produce an adverse affection. This component does not demand a perfect sealed property, and when an adequate insulating property is ensured in the flux in a state, in which the flux is preserved for a long time, the component is not affected even in the presence of the flux. The

seal of the cap aims mainly at mechanical protection. As a way of sealing, it is also possible to press-bond the portions to be sealed with the use of a resistance heating body 15 or the like. In this case, a dispenser is used to perform application along the portions to be sealed, and a fine continuous pattern 12 is formed (Fig. 2(b)).

[0016]

A model with a section A-A' of the pattern enlarged is shown on the right side. Cu balls 1 and Sn balls 2 are held by a flux 4. Subjected to press-bonding from above by the resistance heating body 15, the paste is flattened as shown in Fig. 2(c). A section B-B' as flattened is shown in enlarged scale on the right side. A solder bonded portion 2' between a substrate 6 and a cap 9 defines a gap, which amounts to one Cu ball (about 30 μm). Since press-bonding causes pressed portions to reach a temperature close to a maximum 300 °C, a Cu_6Sn_5 compound can be readily formed in a short time on contact portions between the Cu balls 1 and the substrate 6 and between the Cu balls 1 and the cap 9 insofar as a thick Cu-base plating layer is formed on the cap surface, and compounds can be formed between the Cu balls 1 and the substrate 6 and between the Cu balls 1 and the cap 9 during bonding depending upon an amount of Sn and a condition of heating. Since a width of paste application is narrow, the paste has a thickness amounting to one particle to spread to a width of about 1 mm after pressed, for example, when the paste is applied to a section of 250 μm in width × 120 μm in height.

[0017]

Eutectic Sn-0.75Cu solder balls are beforehand supplied as external connection terminals 11 to this sealed package, the solder paste is positioned and mounted on the printed circuit in the same manner as other parts in a printed state, and surface mounting is performed by reflow. Used as a reflow solder are Sn-3Ag (melting point: 221 °C, reflow temperature: 250 °C), Sn-0.75Cu (melting point: 228 °C, reflow temperature: 250 °C), Sn-3Ag-0.5Cu (melting point: 221 to 217 °C, reflow temperature: 240 °C), and the like. Because adequate strength is ensured between Cu and Cu6Sn5 in the light of results so far obtained for eutectic Sn-Pb solders, the sealed portions will not come off during reflow.

[0018]

In the case where a cap portion is Fe-Ni based and plated with Ni-Au, the growth rate of a Ni-Sn alloy layer is higher above 175 °C than that of a Cu-Sn alloy layer insofar as the Ni layer having a film thickness of 5 μm has been formed (for example, D. Olsen et al.; Reliability Physics, 13th Annual Proc., pp 80-86, 1975), and therefore, an Ni3Sn4 alloy layer is also adequately formed by high-temperature aging. Since Cu6Sn5 is superior to the above alloy layer in terms of properties as an alloy layer, however, it is not desirable to make Ni grow to have a large thickness but it is unnecessary to apprehend a fear of embrittlement due to overgrowth because high-temperature aging cannot be performed for a long period of time. An outline of the growth rate of Sn can be estimated from a data on Sn-40Pb solders, which are lower in alloy layer growth rate than Sn and have many achievements. The growth rate of the

Sn-40Pb solder relative to Ni is at most 1 μm per 10 hours even at 280 °C in the case of a short time (there is also some data of 1 μm per 8 hours at 170 °C), and therefore embrittlement is not problematic. A large alloy layer growth rate is rather desirable. Meanwhile, there is a data, in which the growth rate of the Sn-40Pb solder relative to Ni is 1 μm per 6 hours at 170 °C (simply assuming a solid state, conversion results in a growth of 1 μm per one hour at 230 °C).

[0019]

Also, Sn-base solders (for example, Sn-3Ag, Sn-3Ag-0.5Cu, Sn-0.5Cu) will do in place of Sn. Because the former is lower in melting point than Sn, the alloy layer growth rate in the former tends to become high at high temperatures.

[0020]

In addition, while Au-20Sn bonding is used for die bonding, it is believed that the larger an area, the more advantageously such bonding can be developed. Since gaps between bonded portions are determined by a diameter of balls having a high melting point, control can be optionally performed. Rubbing pellet bonding of Si chips is also used for die bonding, and some bonding involves a solder thickness as thin as 10 μm. While it is thought that even a hard material base solder constitutes no hindrance in practical use since a material, such as Au-20Sn, hard to be deformed has been used for solders in many achievements, it is thought that there is caused no problem insofar as die-bonded portions do not come off during reflow in subsequent processes. It is possible that

alloys between a Si chip (Cr-Cu-Au and Ni plating are possible as a metallized layer on a back surface of the chip) and Cu balls and between Cu balls and a Ni-Au plating on tabs of lead frames be either of Cu and Ni. Since the alloy layer growth is small during aging and at the time of soldering, there is no problem in terms of strength.

[0021]

(Embodiment 3)

Some bonded portions suffice to withstand during reflow in subsequent processes, and so it is thought that stress is small. Therefore, instead of using metallic balls, connection terminals are roughened at one or both sides thereof to form projections of Cu, Ni, or the like, whereby in addition to the anchoring effect, bonding obtained by formation of compounds during aging can be further expected. The anchoring effect of the projections and formation of compounds on contacted portions are achieved by using a dispenser to apply a solder onto terminals, melting the solder while using a resistance-heating body to cause intrusion of the projections from above, and further carrying out aging, whereby strength enough to withstand stresses during reflow can be provided. In Fig. 3(a), a surface of a Cu pad 18 on a substrate 19 is roughened by etching 20, and a paste of a Sn-base solder 2 is applied on the surface. Likewise, Cu plating is applied to a back surface of a chip 17 or the like, and the surface is roughened by etching 20. In Fig. 3(b), reflow and further aging are performed in a state of temporary fixation caused during heating and pressurization

whereby compounds are formed on contacted portions to strengthen the same. Therefore, the portions will not come off during reflow in subsequent processes, in which external connection terminals are connected to terminals on the substrate.

[0022]

(Embodiment 4)

In Au-Sn bonding, in which an increase in concentration is caused by aging and there is compound change in about three stages from low temperature to high melting-point side, various compounds are formed at relatively low temperature in a range, in which temperature is less varied. In Au-Sn bonding, a well-known composition is Sn-80Au (280 °C, eutectic), and a composition of Sn, in which the eutectic temperature of 280 °C is maintained, ranges from about 10 % to 37 %. Embrittlement tends to demonstrate itself when Sn is increased. It is thought that a composition of Sn, realization of which can be expected with a base of less Au, ranges from 55 % to 70 %. While a 252 °C phase appears in this range of composition (Hansen; Constitution of Binary Alloys, McGraw-Hill 1958), it is thought that the purpose can be achieved also in this range of composition because the possibility that portions having been connected together in the preceding process reach 252 °C during bonding in a subsequent process is low. Compounds are in a range, in which ones from $AuSn_2$ to $AuSn_4$ are formed. Such compounds can be applied to die bonding or sealed portions of a cap. Fig. 4 shows a model of a section, in which Ni(2 μm)-Au(0.1 μm) plating is beforehand applied to a back surface of a Si chip 25, for example,

Ni(2 μm)22-Sn(2 to 3 μm)23 plating is applied to a tab on a lead frame 19. In die bonding performed in a nitrogen atmosphere while being subjected to heating under pressure, and further aging, a part of Ni is consumed for a Ni-Sn alloy layer and the remainder of Sn forms an Au-Sn alloy layer. When Sn is large in content, a low eutectic point (217 °C) of Sn and $AuSn_4$ is formed, so that it is necessary to control Sn in content to prevent formation thereof. Although a complex alloy layer is formed, by performing heat treatment at 300 °C or higher to form a compound having a smaller content of Sn than that of $AuSn_2$, a melting point of 252 °C or higher is ensured, and therefore it is thought that there is caused no problem in the subsequent reflow process.

[0023]

As described above, the use of that system, in which a melting point is increased by diffusion during aging although bonding is performed at low temperatures, can realize bonding of high reliability on a high-temperature side in temperature-hierarchical bonding.

[0024]

In addition, metal balls having been described heretofore may be any one of balls containing a single-element metal (for example, Cu, Ag, Au, Al, Ni), alloys (for example, Cu alloys, Cu-Sn alloys, Ni-Sn alloys), compounds (for example, Cu_6Sn_5 compound), or a mixture thereof. That is, any one of the above substances will do insofar as it generates compounds between it and molten Sn to be able to ensure bonding between metal balls. Accordingly, metal balls

are not limited to ones of one kind but may be a mixture of metal balls of two or more kinds. Metal balls may be ones treated with Au plating, or Ni-Au plating, or single-element metal, such as Sn, plating, or alloy plating containing Sn. Also, resin balls, of which surfaces are treated with any one of Ni/Au, Ni/Sn, Ni/Cu/Sn, Cu/Ni, and Cu/Ni/Au plating, may be used. A stress relieving action can be expected by mixing the resin balls.

[0025]

Also, solder balls are not limited to Sn solder balls but may be eutectic Sn-Cu base solder balls, eutectic Sn-Ag base solder balls, eutectic Sn-Ag-Cu base solder balls, or these base solder balls, to which one or more of In, Zn, Bi, and so on are added. Also in this case, Sn constitutes a major part of a resultant composition, so that it is possible to generate desired compounds. Solder balls of two or more kinds may be mixed.

[0026]

[Effect of the Invention]

According to the invention, it is possible to realize solder bonding on a high-temperature side in temperature-hierarchical bonding.

[Brief Description of the Drawings]

[Fig. 1]

Fig. 1 is a sectional view of a model showing materials and a structure of a paste for bonding.

[Fig. 2]

Fig. 2 is a view showing a section model of an applied example,

paste supplying method and a model of a bonded state.

[Fig. 3]

Fig. 3 is a sectional view showing the case of application to a surface etching pattern.

[Fig. 4]

Fig. 4 is a sectional view showing the case of application to plating which is easily alloyed.

[Description of Reference Numerals]

1: Cu balls

2: Sn balls

3: molten Sn

4: flux

5: Sn plating

6: substrate

7: Au-20Sn solder

8: wire bonding

9: cap

10: bonded portion

11: external connection terminal

12: printing pattern

13: component

15: resistance heating body

17: chip

18: Cu pad

19: substrate

20: etching

21: molten solder

22: Ni plating

23: Sn plating

24: Ni-Sn plating

25: Si chip

[Title of Document] Abstract

[Abstract]

[Problem]

It is an object of the invention to provide an electronic device fabricated with a completely new solder bonding. In particular, the object is to realize solder bonding on a high-temperature side, in temperature-hierarchical bonding.

[Solving Means]

In order to attain the above-mentioned object, the invention provides an electronic device having a structure bonded by using a paste, which is a mixture of first balls being one or more kinds of balls containing a single-element metal, alloys, compounds, or a mixture thereof, and second balls being one or more kinds of Sn solder balls, eutectic Sn-Cu base solder balls, eutectic Sn-Ag base solder balls, eutectic Sn-Ag-Cu base solder balls, and solder balls formed by adding one or more of In, Zn, Bi, and the like thereto.

[Selected Figure] Figure 1